

TAILORING THIN FILM-LACQUER COATINGS FOR SPACE APPLICATIONS

Wanda C. Peters, George Harris,
Grace Miller, and John Petro
Swales Aerospace, Inc.
Beltsville, Maryland 20705

ABSTRACT

Thin film coatings have the capability of obtaining a wide range of thermal radiative properties, but the development of thin film coatings can sometimes be difficult and costly when trying to achieve highly specular surfaces. Given any space mission's thermal control requirements, there is often a need for a variation of solar absorptance (α_s), emittance (ϵ) and/or highly specular surfaces. The utilization of thin film coatings is one process of choice for meeting challenging thermal control requirements because of its ability to provide a wide variety of α_s/ϵ ratios. Thin film coatings' radiative properties can be tailored to meet specific thermal control requirements through the use of different metals and the variation of dielectric layer thickness. Surface coatings can be spectrally selective to enhance radiative coupling and decoupling. The application of lacquer to a surface can also provide suitable specularity for thin film application without the cost and difficulty associated with polishing.

KEY WORDS: Thin Films, Lacquer, Thermal Radiative Properties

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1. INTRODUCTION

Throughout the history of the space program, there have been many thermal control challenges, which required innovative space system designs in order to maintain operating temperatures. The space environment (i.e., ultraviolet (UV), atomic oxygen (AO), and charged particles) influences the selection of thermal control coatings and materials. The instability of materials resulting from exposure to the space environment can cause failure of operating systems. Therefore, space systems must be designed to operate within specified temperature limits and space environments over the lifetime of the mission.

Space systems utilize thermal controls to maintain operating temperature requirements. Thermal controls are designed to be passive or active. Passive controls require the utilization of materials that reflect or absorb solar energy to maintain temperature control. Passive control materials require good environmental stability and the desired solar absorptance/emissivity (α_s/ϵ) ratio. Active controls require the utilization of heaters and/or louvers to maintain temperature control.

The utilization of thin film and lacquer coatings is a passive thermal control approach to maintaining operating temperatures. Thin films have been used widely in space applications and have the capability of varying thermal radiative properties by adjusting α_s/ϵ ratios [1]. The solar absorptance of thin films can be varied through the utilization of different metals. The emittance of thin films can be altered by variation of dielectric layer thickness. The thicker the dielectric layer, the higher the normal emittance value. The dielectric layer is non-absorbing, and as a result the solar absorptance is unaffected by the varying thickness. However, variations in metals or dielectric layers are not the only factors that influence the thermal radiative properties of thin films.

Solar absorptance values are also influenced by the substrate's surface texture. Rough surfaces can exhibit a variety of reflectance patterns due to the diffuse nature of the finish. When trying to tailor thin films, the thermal radiative properties' reproducibility and predictability are important. Specular surfaces are more reproducible when thin film coatings are applied; therefore, they produce more predictable properties. When a thin film of metal (i.e., aluminum, gold, or silver) is applied to a surface, the more specular the surface is, the higher the reflectance will be. This higher reflectance yields a lower α_s value. Highly specular surfaces also produce low bi-directional reflectance distribution function (BRDF) values.

For highly specular surfaces, thin films require smooth or polished surfaces. The polishing process for obtaining a highly specular surface can be very time consuming. When polishing a surface, it can be very difficult to obtain the desired level of specularity. This results in the need to evaluate surface finish and often undergo additional polishing, which in turn, increases cost. The amount of time and materials associated with undergoing several polishing series can cause the process to be extremely costly. In addition, there are some materials used for space applications that cannot be polished and have a rough surface texture that is not conducive to highly specular surfaces. Lacquers can be used to coat a wide variety of surfaces, from a smooth surface to an extremely rough surface, and still obtain a highly specular surface. Lacquer coatings have demonstrated the ability to provide a suitable specular surface for thin film application.

2. LACQUER COATING DEVELOPMENT

The goal of using a lacquer coating process is to develop the capability of obtaining a highly specular surface without the cost, and sometimes difficulty, associated with polishing surfaces. The early applications of thin films to lacquer displayed adhesion problems. It was sometimes difficult to get the thin film coating to adhere to the lacquer in an uniform manner. This problem has been eliminated through a revised coating process that provides for better adhesion and uniform specularity.

To obtain a highly specular surface, the lacquer is first sprayed onto a substrate. The lacquer then undergoes a bakeout to harden the coating and remove excess water. At the conclusion of the bakeout, the lacquer is ready for the application of a thin film coating. Once the lacquer has been properly prepared, a thin film coating is applied in vacuum using standard vapor deposition techniques.

It is important to note that the specularity of the lacquer surface can be influenced by the cleanliness of the bakeout. If the oven is not clean, particles may imbed into the surface of the lacquer during the bakeout and create a rough surface finish. A smooth surface finish is required for a highly specular surface.

It is also important to remove excess water from the surface of the lacquer. If excess water remains in the lacquer, during thin film application, the water can rise to the surface and form a barrier between the lacquer and thin film. If this occurs, the water may affect the coating's uniformity and adherence to the lacquer.

This lacquer coating process was recently used to prepare aluminum substrates for laboratory testing. After the application of the lacquer, the samples were coated with vapor deposited aluminum (VDA), vapor deposited gold (VDG), and silver composite coating (Ag Composite). The Ag composite coating formulation selected for laboratory testing was Al_2O_3 (500Å)/Ag (1000Å)/ Al_2O_3 (15000Å)/ SiO_2 (5100Å) [1]. The Al_2O_3 (500Å) layer served as an adhesion layer for Ag and was applied to the aluminum substrate prior to the deposition of the Ag. These samples were then tested to evaluate their properties.

3. TESTS

3.1 Specularity

Bi-directional reflectance distribution function (BRDF) is used to describe the reflectance light patterns of a given surface. The sample's reflective light distribution is measured as a function of wavelength, power, angle of incidence, absorptance, transmittance, surface finish, surface uniformity, index of refraction, and contamination [2]. BRDF is used to measure the specularity, uniformity and cleanliness of the surface. The approach is to illuminate the sample with a single beam of light at a known angle of incidence and measure the light reflected over a wide range of reflection angles. Highly specular surfaces reflect light predominately in one direction, whereas diffuse samples reflect light in all directions.

3.2 Thermal Radiative Properties

3.2.1 Solar Absorptance. The AZ Technology's LPSR-200 instrument was used to perform the reflectance measurements and solar absorptance calculations. The solar absorptance is calculated in accordance with ASTM E903-82. The LPSR-200 measures the reflectance of the sample's surface at a 15° angle of incidence over the spectrum range from .25 to 2.5 microns. The instrument measurement accuracy is $\pm .02$ for α_s values.

3.2.2 Normal Emittance. The Gier-Dünkle DB-100 is used to measure the normal emittance value of surfaces. The normal emittance measurement is made in accordance with ASTM E408-71. This measurement is made at room temperature over the spectrum range of 5 to 40 microns. A newly coated vapor deposited aluminum mirror is used as a reference for the normal emittance measurements. The DB-100 is set to a normal emittance value of 0.020 using the VDA reference mirror. The sample is then measured after the instrument's calibration process. The instrument measurement accuracy is $\pm .02$ with an instrument reproducibility of $\pm .001$ for ϵ_n values.

3.3 Adhesion

A drip test in liquid nitrogen (LN2) was designed to evaluate the coating's adhesion. The VDA over lacquer on aluminum sample was dipped in liquid nitrogen. This process was used to test the adhesion by exposing the sample to a rapid temperature change. The sample was emerged in LN2 until the sample temperature stabilized. Once the LN2 stopped bubbling, the sample was perceived to have reached temperature equilibrium. From this point, the sample remained in the LN2 for five minutes and then was removed from the LN2 for examination.

3.4 Atomic Oxygen

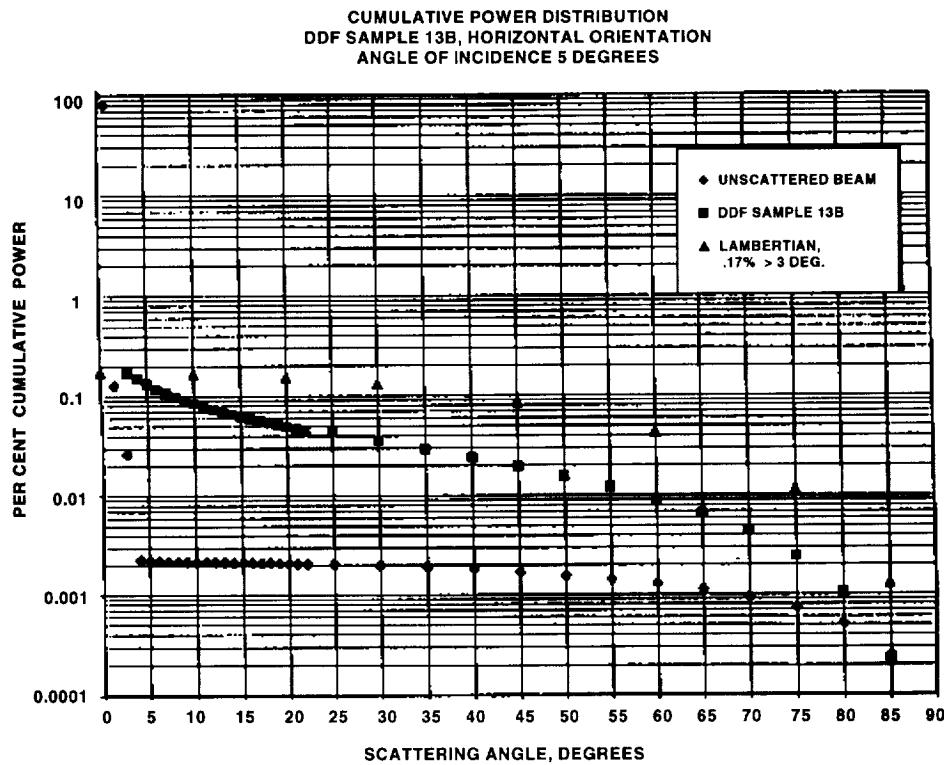
The asher test is designed for exposing samples to atomic oxygen (AO) in the form of a plasma. The etcher used for the asher test is a PlasmaPrepX, parallel plate plasma etcher. The etcher generates a plasma in which oxygen is pumped. Given a specified energy level and fluence, the asher can simulate AO in lower earth orbit (LEO). The fluence level used for the test was obtained from the Hubble Space Telescope Servicing Mission Two (SM2) data [3]. The samples were exposed for approximately three hours. A standard Kapton®-HN specimen is used as an erosion control for the asher test.

4. RESULTS

4.1 Specularity

An aluminum honeycomb substrate was coated with VDA over lacquer. A BRDF measurement was made of the sample to determine the specularity of the surface. Chart 1 shows that at 3° scattering angle and above, the VDA/lacquer coating diffuse light portion is .17% or less [4]. From the diffuse measurement, the specular portion is calculated to equal 99.83%. The unscattered beam measurements are provided to confirm that the VDA/lacquer sample results are not due to instrument noise or to the shape of the beam. The Lambertian measurements represent a classic diffuse surface scattering profile.

Chart 1: BRDF Power Distribution [4]



4.2 Thermal Radiative Properties Measurements

Samples were tested to determine their thermal radiative properties. A comparison between the reflectance and thermal radiative properties of a non-polished bare aluminum substrate and a glass substrate was also conducted. Glass substrates provide a good finish for obtaining highly specular surfaces with the application of metallic thin films. The non-polished bare aluminum substrate was coated with lacquer and then coated with a thin film of metal. The glass substrate was coated directly with the thin film of metal. Table 1 contains the measured thermal radiative properties.

Table 1: Thermal Radiative Test Results

	Sample Description	α_s	ϵ_n
1.	VDA over Lacquer on Aluminum Substrate	.09	.02
2.	VDA over Lacquer on Aluminum Honeycomb Substrate	.09	.02
3.	VDG over Lacquer on Aluminum Substrate	.18	.01
4.	Ag Composite Coating over Lacquer on Aluminum Substrate	.07	.69

Chart 2 shows the reflectance curves of a VDA over Lacquer on aluminum compared to a VDA on glass. The thermal radiative properties of both VDA samples are the same and there is no significant difference in their reflectance curves. The aluminum substrate used for the VDA/lacquer sample has a non-polished bare aluminum finish.

Chart 2: VDA over lacquer on a non-polished substrate and VDA on a glass substrate

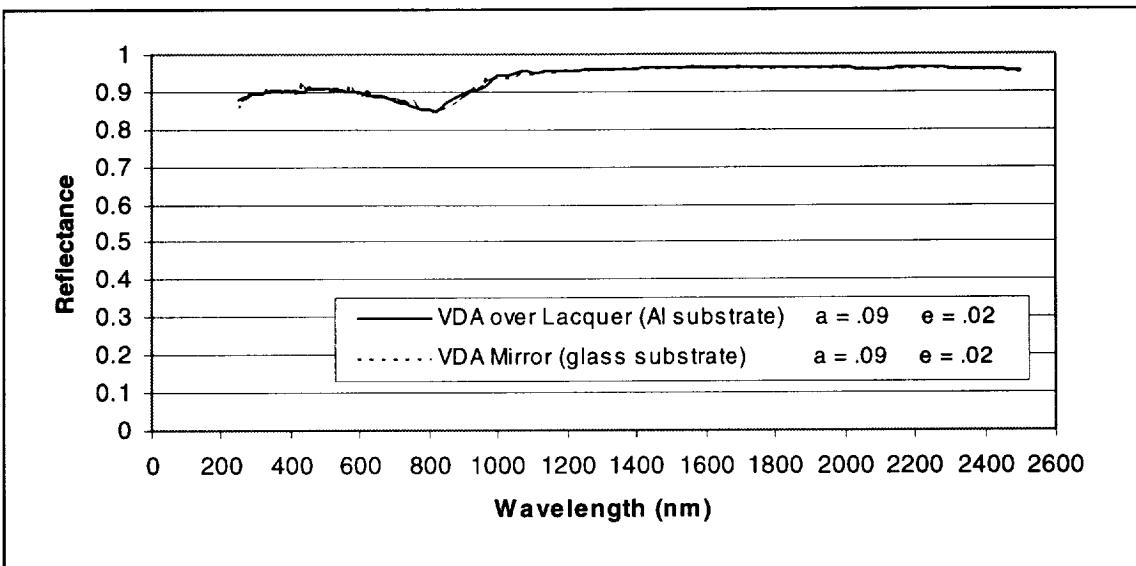


Chart 3 contains the reflectance measurements and thermal radiative properties of VDG over lacquer on an aluminum substrate and VDG on a glass substrate. There are no significant differences between the reflectance curves of the two samples. The thermal radiative properties of the samples are similar.

Chart 3: VDG over lacquer on a non-polished substrate and VDG on a glass substrate

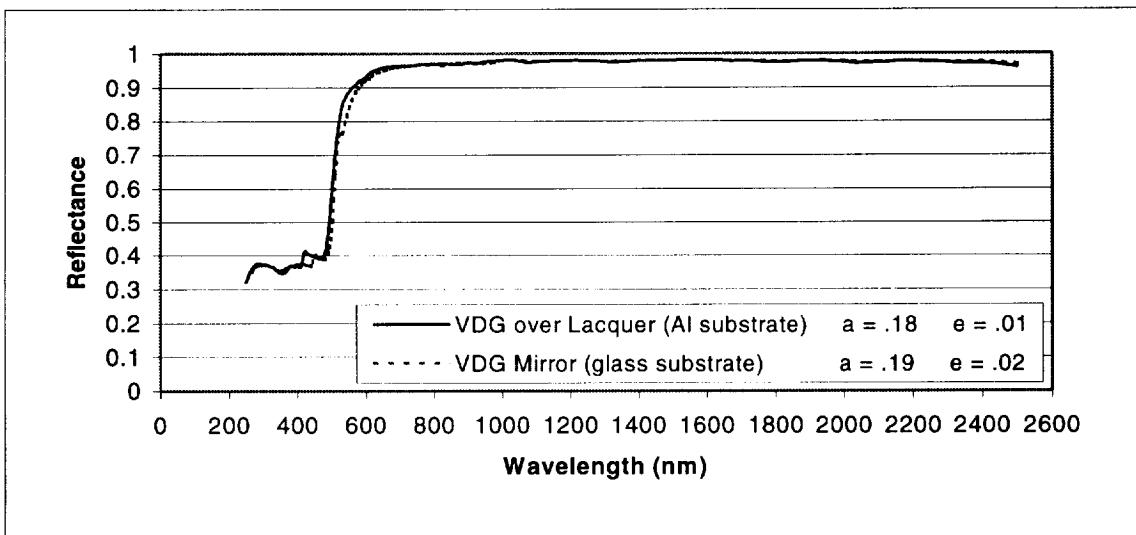
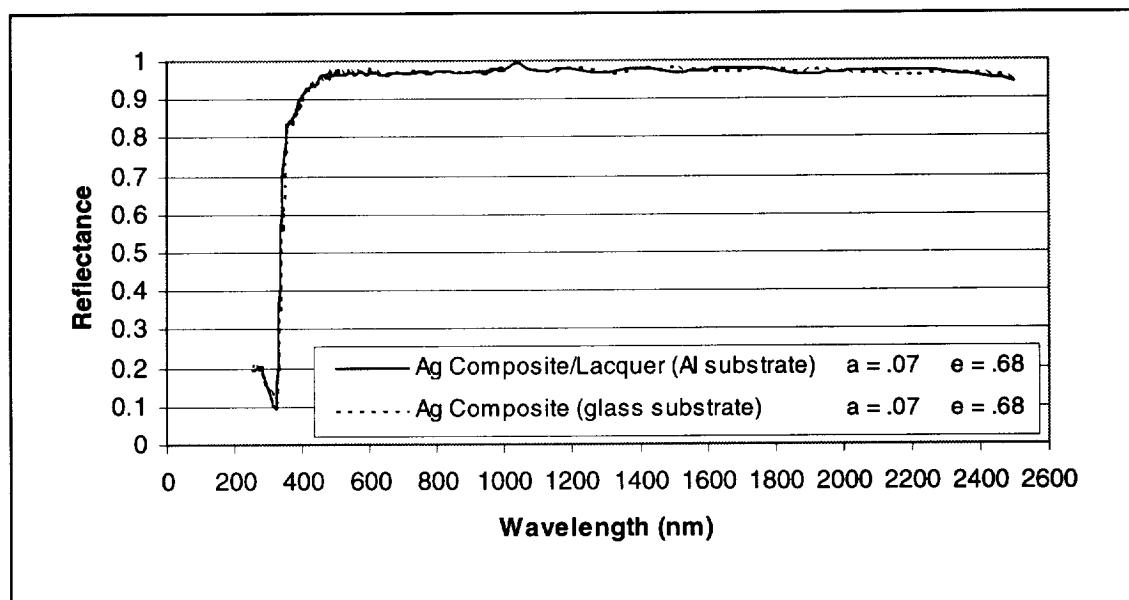


Chart 4 shows the same thermal radiative properties and reflectance measurements for the Ag composite coating samples. The lacquer coating provided the Ag composite coating with a finish that is comparable to a glass finish.

Chart 4: Ag Composite/Lacquer on a non-polished substrate and Ag Composite on a glass substrate



4.3 Adhesion

Upon visual observation of the sample upon removed from the LN₂, there was no flaking or peeling of the VDA from the lacquer. There was no visible flaking or peeling of the lacquer from the substrate. The VDA adhered well to the lacquer.

4.4 Atomic Oxygen

Two lacquer samples, a VDA over lacquer and an Ag Composite Coating over lacquer, were tested in the asher test. Based on the erosion of the Kapton®-HN control, the simulated AO fluence was determined to be 1.3×10^{20} atoms/cm² which is equivalent to the Hubble Space Telescope's SM2 fluence. Chart 5 and Chart 6 show the before and after AO exposure results of the two thin film/lacquer samples. There was no change in the thermal radiative properties of the two samples before and after simulated AO exposure. The reflectance curves of the two samples exhibited no significant change.

Chart 5: VDA over Lacquer AO Exposure Test Results

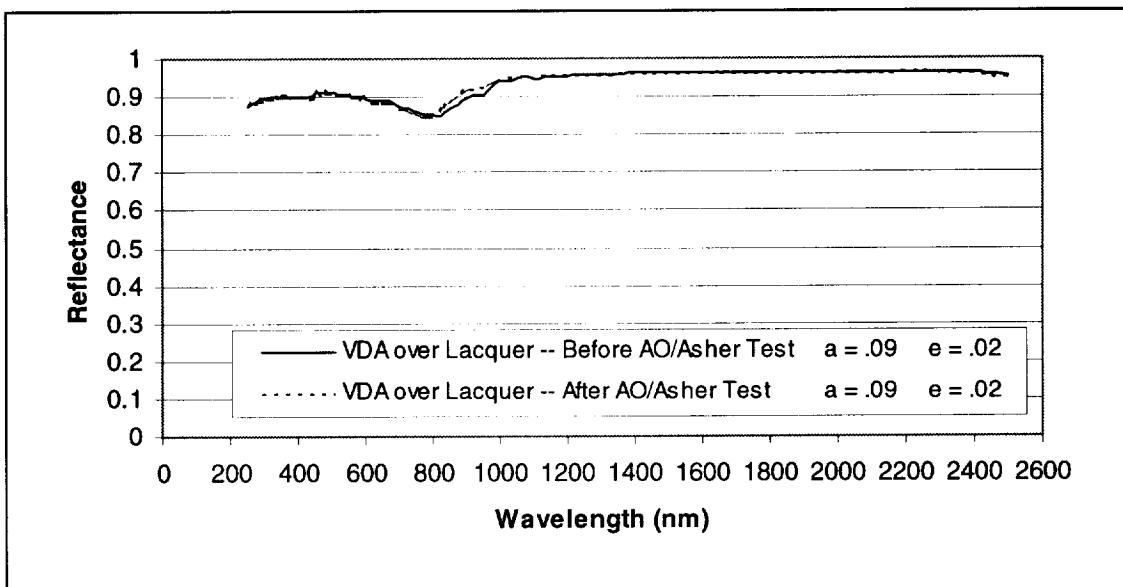
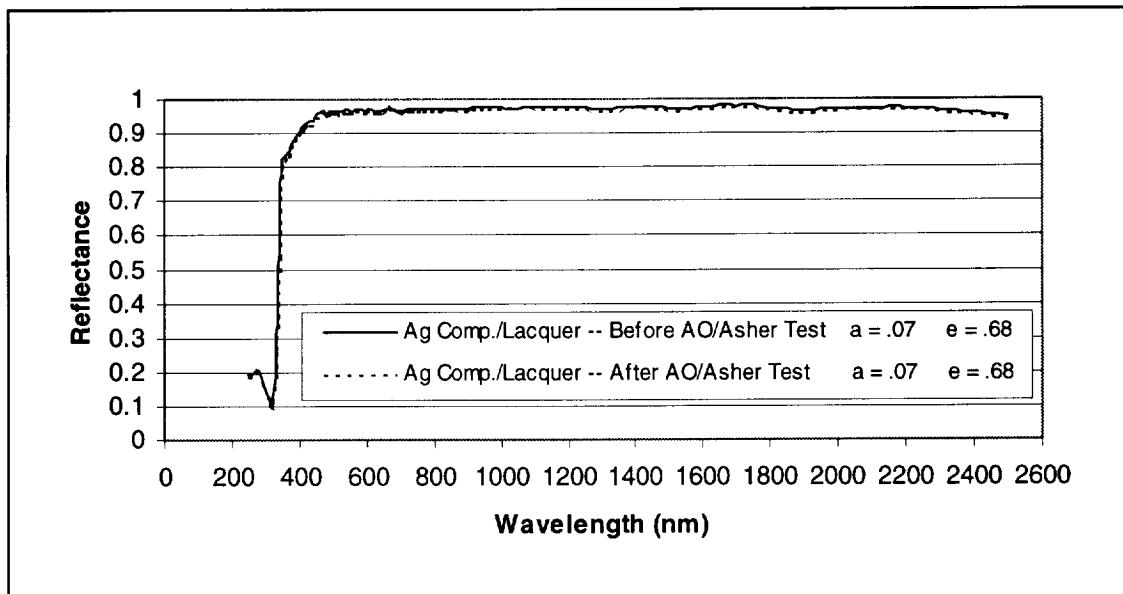


Chart 6: Ag Composite Coating over Lacquer AO Exposure Test Results



5. DISCUSSION

5.1 Space Applications

Lacquers have been applied to aluminum, honeycomb, and fiberglass composite material substrates and flight structures. Lacquers have been used on space missions, such as the Solar and Heliospheric Observatory (SOHO). A VDA over lacquer coating was applied to search coils and flown on the SOHO mission. The search coils' substrates were fiberglass composite material. Lacquer was used on the fiberglass substrate to provide a more specular surface for the application of VDA. The lacquer coating process utilized for the SOHO mission has been enhanced to provide better surface adhesion. Lacquers have also coated the following spacecraft structures: sunshields, NASA's Director's Discretionary Funds (DDF) cooler shields, and DDF cooler doors.

5.2 Future Testing

This paper is reporting the initial findings of current lacquer testing. To fully understand the significance and potential use of lacquers, further testing is required. There are currently plans to have the lacquer coating undergo additional testing. The lacquer coating is presently scheduled for standard outgassing testing. The effect of charged particles is another area of interest in the evaluation of thin film/lacquer samples. Additional atomic oxygen testing, at higher fluence levels, is also planned for the thin film lacquer samples. Furthermore, there are plans to coat different substrates of various surface finishes with the lacquer coating. These samples will undergo specularity, thermal radiative properties, adhesion, simulated AO, outgassing, and charged particle testing.

6. CONCLUSIONS

The current test results of the lacquer coating are very promising. The lacquer coating has demonstrated its potential for being an excellent device for achieving a highly specular surface for thin film applications. Although additional testing is needed to completely evaluate the full potential of the lacquer coating process, the initial test results have shown that the application of a lacquer can provide a highly specular surface for tailoring thin films.

The benefit of using a lacquer coating is the flexibility of being able to coat rough surfaces that cannot be polished, as well as smooth surfaces. A lacquer coating provides a suitable specular surface for thin film applications, as long as cleanliness is maintained during bakeout and excess water is eliminated from the lacquer. The lacquer coatings have been utilized in the past. However, lacquers have the potential to be used more widely in space applications with enhancements in the lacquer coating process of better adhesion and higher surface specularity. Lacquers may also provide a more cost efficient means of obtaining a highly specular surface for thin film applications on various surface finishes.

ACKNOWLEDGEMENTS

The authors would like to thank Jack Triolo of Swales Aerospace, Nancy Carosso of Swales Aerospace, and Lon Kauder of NASA-Goddard Space Flight Center for their technical expertise and assistance. The authors would also like to thank Robert Gorman of Swales Aerospace and Jackie Townsend of NASA-Goddard Space Flight Center for providing technical data and testing support for this paper.

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